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The thickness of the cartilage in the hip joint

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INTRODUCTION

The specific stress upon the hip joint has been investigated by many authors. The determination of the size and direction of the resultant of the relevant forces (muscle force and gravity) has been a principal objective of most investigations (Pauwels, 1935; Kummer, 1968, 1969; Amtmann & Kummer, 1968; McLeish & Charnley 1970; Hamacher & Roesler, 1971 *a*, *b*).

On the assumption that functional stress is reflected in structural organization (Roux, 1895; Fick, 1904; Pauwels, 1960), several workers have examined and analysed the morphology of the cartilage of the hip joint. Werner (1897), Kurrat (1977) and Oberländer (1977) determined how thickly the cartilage was distributed over the hip joint head and in the acetabular socket. Using the Hultkrantz (1898) method for producing split-lines, Tillmann (1973) and Molzberger (1973) examined the cartilage of both joint surfaces. The structure of the subchondral bone was described by Knief (1967 *a*, *b*) and Oberländer (1973).

Holmdahl & Ingelmark (1948) were able to prove that cartilage proliferates under functional stress. Furthermore, Ingelmark & Ekholm (1948) and Ekholm & Ingelmark (1952) could demonstrate that cartilage reacts to increased stressing by reversible swelling.

Previous authors have usually concentrated attention on only one element of the hip joint, but the present investigation is concerned with the articular cartilages of both femur and acetabulum in one and the same joint.

MATERIALS AND METHODS

Ten hip joints (femoral heads and acetabula) from five dissecting room subjects embalmed in formalin alcohol were studied. The cartilage thickness of the articular surfaces was measured. Previous investigations (Kurrat, 1977) have shown that this method of embalming has no measurable influence on cartilage thickness. Table 1 shows the age and sex of the subjects. Since the surfaces of the hip joint head and acetabulum are covered with cartilage to different extents (the socket up to the equator, the head far beyond the equator), the sites from which the cartilage samples were to be removed had to be determined in different ways on the two sides of the joint. First, the whole length of the thigh bone in its natural position was determined by the method of Schmitt (1968). The whole length is defined as the distance between parallel planes, one of which is tangential to both condylar surfaces, while the other touches the head at the proximal measuring point of length. Then the centre of the fovea capitis was defined as the pole. After that the head was divided into a system of meridians and latitudes, the longitude 0° going through the proximal measuring point of length. The meridians were spaced at a distance of 30°, the latitudes chosen

Table 1

Subject number	Age	Sex
1	34	Male
2	70	Male
3	63	Female
4	60	Male
5	86	Male

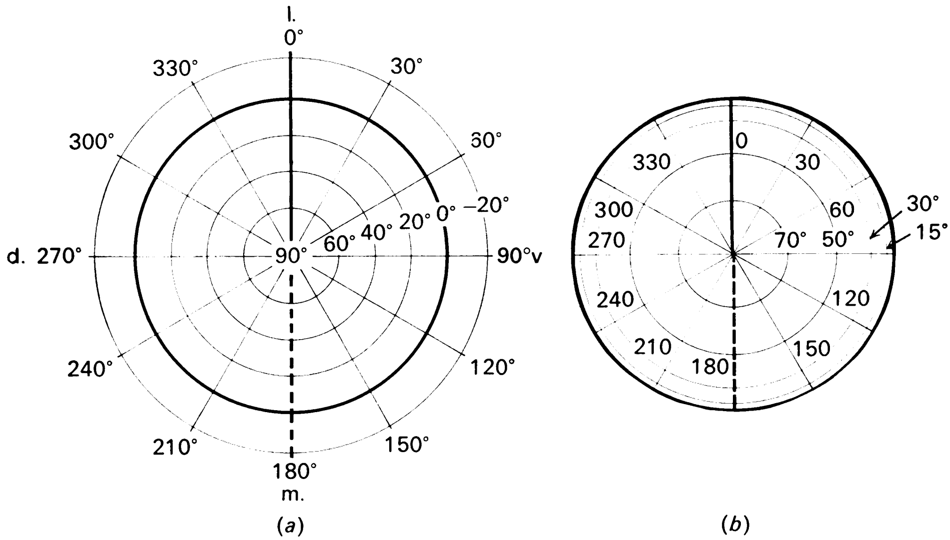


Fig. 1. Grids used to determine the sites from which cartilage was to be removed. (*a*) Stereographic conical projection used for the head. (*b*) Orthographic zenithal projection used for the socket.

were those of 60°, 40° and 20° (the equator = 0°) and beyond the equator, the latitude of −20°. Using a goniometer, samples were taken from the crossing points of the above mentioned meridians and latitudes. For the socket, first the positive slide of a grid was made (meridians spaced at 30°, the latitudes 70°, 50°, 30°, 15°, 0°) in an orthographic zenithal projection with the pole as the centre of the projection (Fig. 1). This was projected into the acetabulum with the longitude 180° in the middle of the acetabular notch. The equator ran along the acetabular edge. As before, samples were taken at the crossing points of the above mentioned latitudes and meridians.

The cartilage samples were extracted with a punch (diameter of the sample from the head 3·5 mm, from the acetabulum 5·0 mm) and then measured under a microscope (Kurrat, 1977). The average of three single measurements was taken as the test result. Figure 2 shows how the thickness is distributed in the system of a stereographic conical projection with the pole as the centre. Since the cartilage thickness differs on the two sides of the joint, different graduations were used. The diameters of both the head and the socket, as well as the neck–shaft angle, were also determined (Table 2).

Table 2

Subject	Femur length (cm)	Neck–shaft angle (deg)	Diameter of head (mm)	Diameter of socket (mm)
1 Right	48·7	127	51	52
Left	49·7	126	50	51
2 Right	44·2	118	49	49
Left	45·3	130	48	48
3 Right	40·4	131	43	45
Left	41·1	131	41	43
4 Right	44·2	124	50	50
Left	44·0	122	49	49
5 Right	50·9	130	52	53
Left	50·7	129	53	53

RESULTS

The cartilage surfaces examined were smooth and with one exception (head of femur in subject 3) showed no signs of osteoarthritis. Table 2 summarizes the macroscopic measurements.

Figures 2(*a–k*) show the distribution of cartilage thickness. The individual values are listed by Kurrat (1977) and Oberländer (1977). In the following account head and socket will be discussed together.

Subject 1 (*Fig.* 2*a*, *b*)

The cartilage of the head of the right femur is thickest (4·4 mm) lateral to the fovea capitis in the region of latitude 60°. On the medial half of the head the cartilage layer decreases rapidly, but in the lateral area a layer of approximately 1·3 mm persists beyond the equator. The socket cartilage has a maximum thickness (2·8 mm) at the outer edge and at 30° longitude. The cornu anterius is relatively short and narrow.

The head of the left femur has a thinner layer of cartilage (maximum 3·4 mm, ventrolaterally, close to the fovea). From here the cartilage gradually decreases in thickness towards the lateral edge of the joint surface; a narrow strip between 2·5 and 1·5 mm thick stretches into the medial head area. All in all, the socket belonging to it also has a rather thin covering of cartilage, the maximum thickness being less than 2·5 mm. Two small areas of the cartilaginous covering in the cornua are remarkable in being relatively thick in comparison with their surroundings.

Subject 2 (*Fig.* 2*c*, *d*)

The cartilage over the right head has its maximum thickness (3·2 mm) at the intersection of longitude 0° and latitude 60°. Ventrolaterally the cartilage decreases in thickness towards the edge of the joint surface. The medial fovea edge shows a thinned out area (about 1·4 mm) which reaches zero thickness towards the equator in the dorsomedial area. The acetabulum only has a small fossa acetabuli; the cartilage is rather thick. The maximum (3·01 mm) is at 60°, at the outer edge.

The head of the left femur shows a distribution of cartilage thickness similar to the right one. There is a maximum (3·1 mm) at the intersection of latitude 60° and longitude 30°. This subject also shows a rapid decrease of cartilage thickness starting from the medial fovea edge. The socket likewise has its maximum (3·25 mm) at the

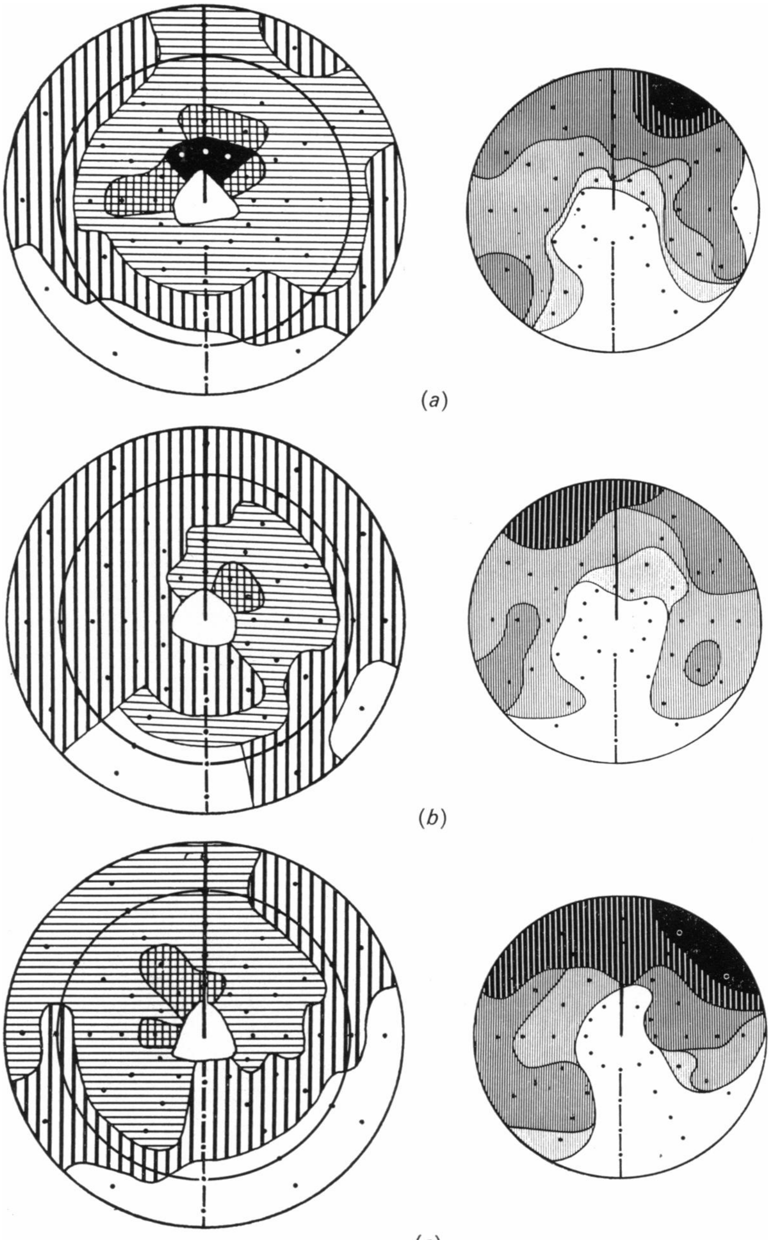
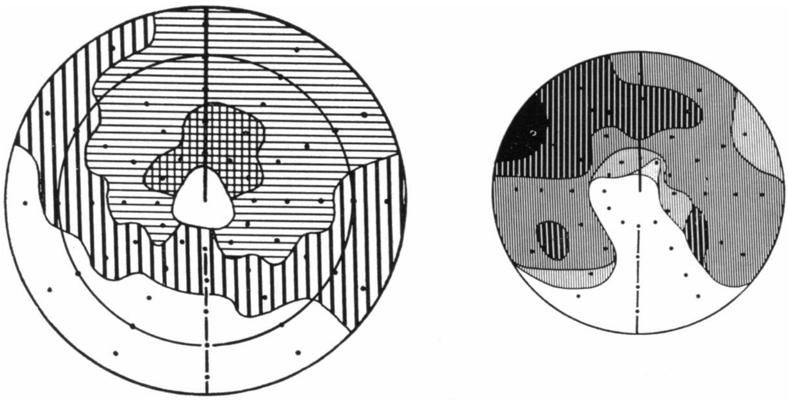
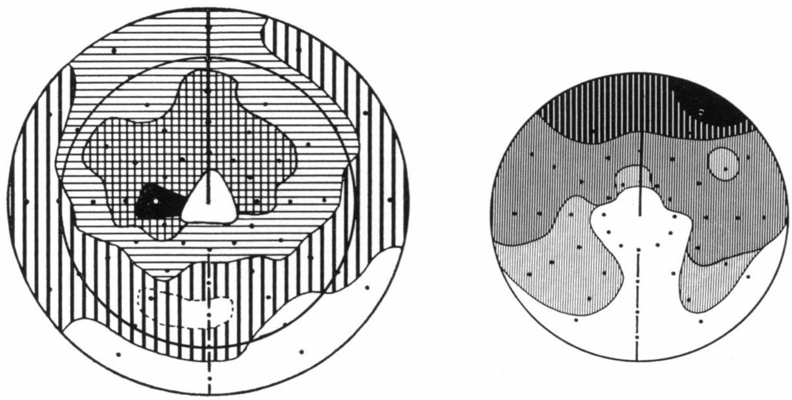


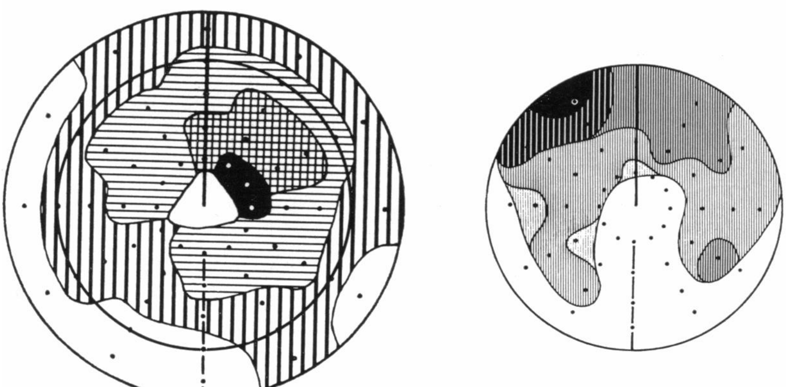
Fig. 2. Distribution of cartilage thickness in the subjects examined. On the left, the femoral heads. On the right, the acetabula. The thick solid line indicates the 0° meridian, the dashed line shows the 180° meridian in the lowest part of the joint elements. Figures *a*, *c*, *e*, *g*, *i* are of the right side; Figures *b*, *d*, *f*, *h*, *k* are of the left side. The thick solid circle in the heads indicates the equator, and has the same radius as the socket margin.



(*d*)



(*e*)



(*f*)

Fig. 2 (*d–f*). For legend see opposite.

edge at 60°. Here also there are distinct relative maxima in the cornua. As on the opposite side, the fossa acetabuli is small.

Subject 3 (*Fig*. 2*e*, *f*)

There is maximum cartilage thickness (4·3 mm) in the ventral area of the right femoral head close to the fovea capitis. An area with cartilage between 2·5 and

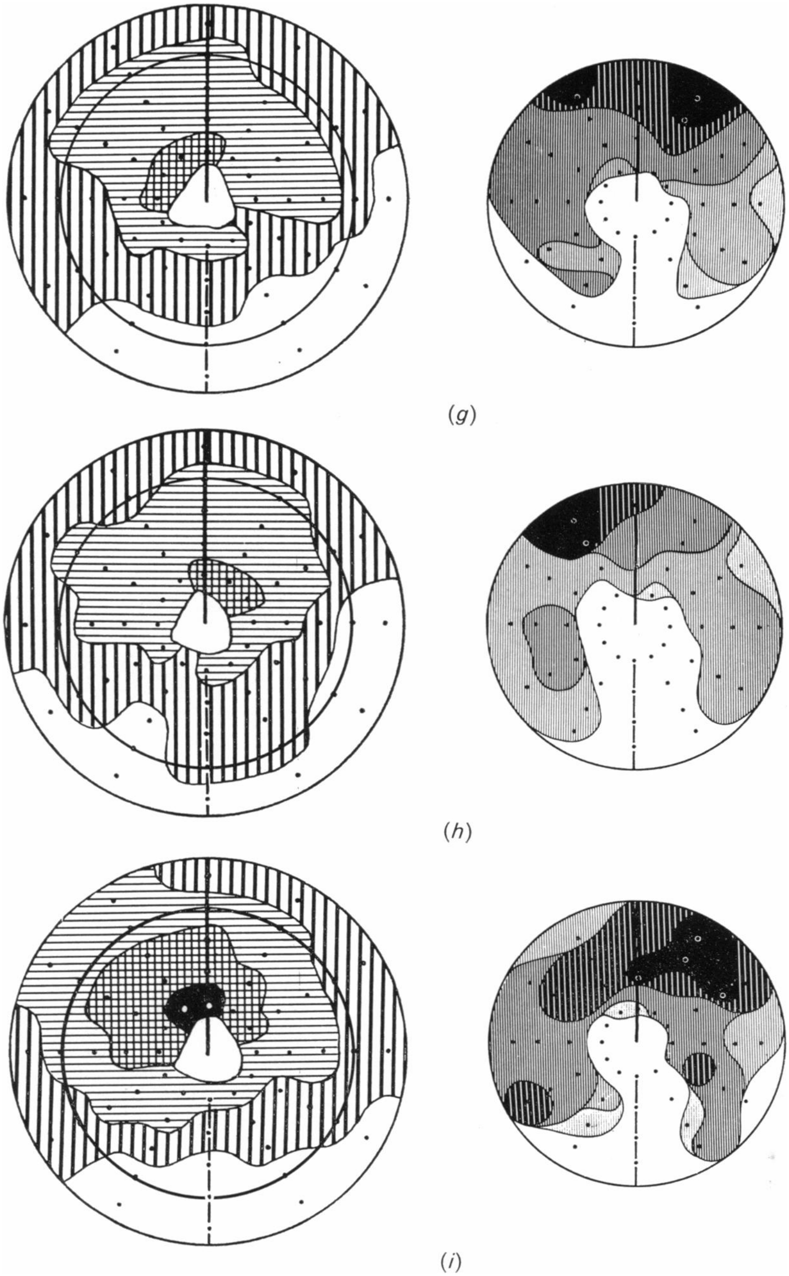


Fig. 2(*g–i*). For legend see p. 148.

3·5 mm thick expands in the dorsolateral sector, whereas in the medial area there is a much thinner layer of cartilage. In the medial head sector at latitude 20°, there are degenerative changes of the cartilage, together with a decreased thickness. The socket shows a very regular distribution of cartilage thickness, with a maximum (3·22 mm) at 30° at the outer edge. The incisura acetabuli is narrow.

The left femur has a similar distribution of cartilage thickness, with a peak value

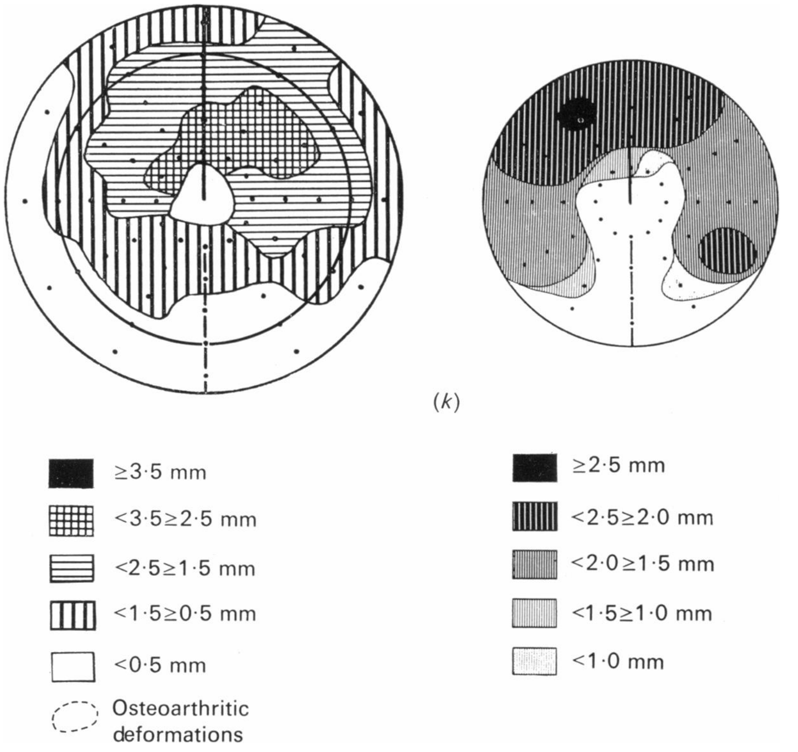


Fig. 2 (*k*). For legend see p. 148.

of 4·1 mm in the ventrolateral head sector. In the dorsomedial head area a thinned out zone (0·8 mm) extends up to the fovea. At the socket, very narrow cornua are noticeable. The covering is not very thick; the maximum thickness (at 30° at the edge) is only 2·6 mm.

Subject 4 (*Fig.* 2*g*, *h*)

The relatively thin cartilaginous covering of the head of the right femur is thickest (3·3 mm) around longitude 30°, close to the fovea capitis. Particularly in the dorsomedial part of the head, the cartilage layer decreases rapidly, so that in this region the cartilage border is situated at the equator. The socket has two thickness maxima (3·26 mm) at 30° and 330°. This contrasts with the remaining layer, which is not very thick. The cornua are relatively short and narrow.

The distribution of cartilage thickness on the head of the left femur is almost identical to that of the right. The acetabulum has a very thin cartilaginous covering. It is thickest (3·02 mm) at 30° close to the edge. The cornu posterius is very narrow.

Subject 5 (*Fig.* 2*i*, *k*)

The thickest cartilage (4·1 mm) of the right femur head is at the lateral fovea edge. Medial from the fovea, cartilage thickness decreases rapidly. All in all, the cartilaginous covering of the socket is very thick; however, no high peak values are reached (2·76 mm). There are two relatively high values in the cornua. The fossa acetabuli is rather small.

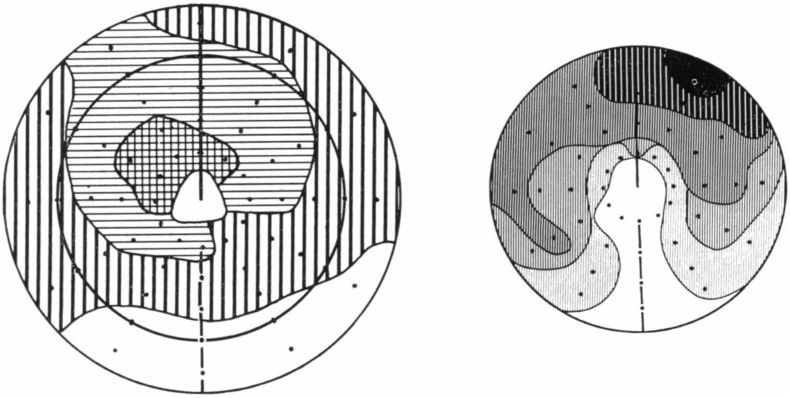


Fig. 3. Average distribution of cartilage thickness. The scale is the same as in Fig. 2.

For the left head the cartilage thickness maximum (3·3 mm) is similar to that on the right. A thinned out area of 1·2–1·4 mm extends in the medial head sector up to the fovea capitis. The socket, too, is similar to the one on the right side. All in all, the cartilage is quite thick here as well (maximum, 2·53 mm). With both sockets, the maximum is not at the edge, but at the latitude 30°.

Since head and socket do not show patterns of cartilaginous covering which differentiate strongly or exclude each other, it is admissible to compute an average distribution pattern for the cartilage thickness. For this purpose, the average thickness values for the cartilage samples at all removal sites were calculated. At sites without a cartilage covering, the value zero was used. The general pattern for the average distribution of cartilage thus obtained is as follows (Fig. 3). The head has an almost concentric gradation of cartilage thickness, the centre lying ventrolaterally from the fovea capitis between latitudes 60° and 40°. The socket also shows a regular and concentric distribution of cartilage thickness, with the centre at longitude 30° (ventral) and around latitude 15–30°.

DISCUSSION

In this investigation the thicknesses of the articular cartilages of the hip joint have been measured. In the following discussion the results will be discussed from both anatomical and functional standpoints. In addition to the comparison of individual values (Fig. 2), a comparison of the calculated average distribution of cartilage thickness, as shown for both head and acetabulum in Figure 3, seems to be particularly useful for deriving general principles.

First of all, it is obvious that the cartilage over both socket and head is thickest in the ventrolateral quadrant, whereas the area with the thinnest covering in both was in the lower region (for the head, medial to the fovea; for the socket, at the caudal edge of the facies lunata, close to the fossa). Between these extremes there is a transitional area in which the cartilage thickness decreases concentrically. It must be pointed out that the centres of the determined cartilage distribution are not identical with the central points chosen for the graphic representation (fovea capitis and the centre of the fossa acetabuli). The thickest cartilage of the head is situated around the point where the axis of the femoral neck goes through the head. The

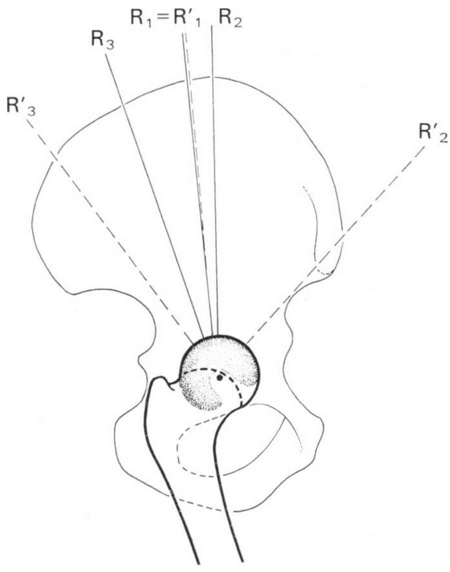


Fig. 4. The direction of the resultant force in the hip joint in different positions. The solid lines show the direction of the resultant in relation to the socket, the dashed lines in relation to the head. The joint element referred to is thought of as fixed, whilst the other one is regarded as moving. (After Kummer, 1970.)

socket is thickest close to the edge, in the upper joint sector. The thickness decreases concentrically around these points, at the head in almost circular contours, at the socket in contours which are diminutive replicas of the facies lunata.

Since, according to Holmdahl & Ingelmark (1948), Holmdahl (1953), Kummer (1961), and Pauwels (1960), cartilage thickness is dependent on the degree of functional stressing, it should be possible for the relative dimensions of local stressing to be inferred from the distribution of cartilage thickness. On this basis the areas with the highest stressing for both elements of the joint are in the front, upper and lateral quadrants of the two joint surfaces, though not in areas which are apposed in the 'normal position of the joint'. In relation to the hip joint stress resultant during one-legged stance (Pauwels, 1976), the area with the thickest cartilage over the head is shifted towards the medial side, for the socket towards the lateral side. However, this observation needs to be related to the contact surfaces in different positions of the hip joint. In this connexion, the extent to which the resultant is shifted by its change of direction seems to be of importance. Investigations by Kummer (1970) showed that the hip joint resultant has a smaller angle of deflexion in reference to the socket than to the head of the femur (Fig. 4). Firstly, this explains the incomplete cartilaginous covering of the acetabulum (Kummer, 1969; Tillmann, 1969); secondly, it accounts for the fact that, whilst the cartilaginous covering of the head is usually complete, that over the medial sector, which undergoes a lesser degree of functional stressing, is relatively thin.

Additional evidence for the view that cartilage thickness is related to the degree of functional stressing is afforded by the underlying bone structure. Kurrat (1977) was able to demonstrate that the cartilage layer was thickest near to the medial margin of the pressure area of the femoral spongiosa (Pauwels, 1954; Harrison, Schajowicz & Trueta, 1953). Oberländer (1973, 1977) noticed a great correspondence between the thickness of the cartilage and the X-ray density of its subchondral bone. The graphic representation for each subject in Figure 2 indicates that the distribution of cartilage thickness varies somewhat from one individual to another. To analyse this variation one would need to know a lot about the life style of the individuals and the type of stressing to which their joints were habitually subjected. Future investigations will examine the stress patterns of the joint cartilage in models, in the hope of explaining why the cartilage of the head is thicker than that of the socket, and why the thickest areas of cartilage seem to have different locations on the two sides of the joint and in the joints of different subjects.

SUMMARY

The pattern of distribution of cartilage thickness in corresponding femoral heads and acetabula was ascertained in ten hip joints. The differences between individual acetabula and their corresponding heads were small enough for it to be admissible to calculate an average distribution pattern for head and socket. Comparison of these patterns showed that: (*a*) The maximum thickness is found at points in the ventrocranial area of the acetabulum and the ventrolateral area of the head. (*b*) From these points the cartilage thickness decreases concentrically. (c) In the 'natural position' of the hip joint the points of maximum thickness of head and acetabular cartilage do not correspond. In relation to the line of the hip joint 'force resultant', the area with the thickest cartilage on the head is slightly shifted towards its medial side, and on the socket slightly to the lateral side. It is not possible fully to explain these results on the basis of existing conceptions about the functional stressing of the hip joint.

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